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PB-299 297

Critical Thermal Maxima of Two Species of Estuarine Fish

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17 Dec 76

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA-600/J-77-160	2. JOURNAL ARTICLE	3. RE PB 299297
4. TITLE AND SUBTITLE Critical Thermal Maxima of Two Species of Estuarine Fish		5. REPORT DATE 1977 (Issue Date)
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) D. Everich and J.G. Gonzalez		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Environmental Research Laboratory Narragansett, RI 02882		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Environmental Research Laboratory Narragansett, RI 02882		13. TYPE OF REPORT AND PERIOD COVERED journal reprint
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES Marine Biology, 41, pp. 141-145, 1977		
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17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS <i>Marine fishes acclimation Estuaries thermal pollution plant tolerance</i>	b. IDENTIFIERS/OPEN ENDED TERMS <i>Critical thermal Maxima</i>	c. COSATI Field/Group
REPRODUCED BY NATIONAL TECHNICAL INFORMATION SERVICE U.S. DEPARTMENT OF COMMERCE SPRINGFIELD, VA. 22161		
19. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS (This Report) 20. SECURITY CLASS (This page)	21. NO. OF PAGES 7 22. PRICE A02-A01

Critical Thermal Maxima of Two Species of Estuarine Fish

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Abstract

Critical thermal maxima (CTM) were determined for winter flounder (*Pseudopleuronectes americanus*, Walbaum) and scup (*Stenotomus chrysops*, L.), acclimated to ambient water temperature or constant increments above ambient. The acclimation regimes simulated a natural environment by tracking the temperature fluctuations in Point Judith Pond, a small Rhode Island estuary. An elevation in CTM from 30.2° to 35.6°C was observed for scup as the mean acclimation temperature increased from 14.8° to 22.2°C. CTM for flounder increased from 26.4° to 32.4°C over an acclimation range of 4.2° to 23.0°C. The use of CTM studies for predicting the effects of heated effluents is discussed.

Introduction

Critical thermal maximum (CTM) is the temperature at which an organism suffers total loss of equilibrium when experimentally subjected to rapidly rising water temperature. The rate of temperature increase from previous acclimation temperature must be continuous and rapid, but sufficient to allow simultaneous increase of internal body temperature and water temperature (Hutchison, 1961).

CTM for fish and amphibia have been determined to explore questions about temperature acclimation, seasonal changes in temperature response, and to compare species and populations from different habitats (Hutchison, 1961; Heath, 1967; Hutchison and Ferrance, 1970; Otto, 1974). Also, it has been suggested that CTM is an appropriate index to predict the response of organisms encountering the effluent plume of a steam generating plant (Mihursky and Kennedy, 1967; Gift and Westman, 1971). The purpose of this study is to measure and compare the CTM of two species of estuarine fish and evaluate the use of this measurement for predicting the effects of thermal effluents on fish.

Materials and Methods

One hundred and fifty juvenile winter flounder (*Pseudopleuronectes americanus*, Wal-

baum), 33 g average wet weight, were collected by otter trawl from Point Judith Pond, Rhode Island (USA), and 150 juvenile scup (*Stenotomus chrysops*, L.), 10 g average wet weight, were collected by the same method from Narragansett Bay, Rhode Island. Prior to experimentation, the fish were held for 1 to 3 weeks in continuously-renewed unfiltered seawater of ambient (water) temperature at the Research Barge, Point Judith Pond.

The water-temperature control system described by Beck (1973) was used for acclimating the fish to desired test temperatures. This system consists of three 757 l circular aquaria, each supplied with seawater that has been heated to a constant increment above the ambient water temperature cycle. Another similar aquarium was supplied with ambient temperature seawater. Water in each tank was unfiltered and continuously renewed at a rate of 7 to 8 l/min.

Fish were transferred from the holding facility to the temperature control system, 30 fish in each aquarium. Each group was gradually brought to the desired test temperature by 5°C additions, allowing 3 to 5 days for adjustment to each increase. Then they were held at the final temperature for 3 to 5 weeks to insure complete acclimation. Test temperatures selected for the scup experiments in November 1972 were ambient and increments of 5, 10 and 15°C above

ambient. For experiments with winter flounder, the February 1973 study was conducted at ambient temperature only, and the June 1973 temperature regimes were ambient and increments of 5 and 10 °C above ambient.

Following test-temperature acclimation, CTM determinations were conducted on each fish individually, according to the method described by Hutchison (1961). The fish was removed from the acclimation tank with a dip net and placed immediately in the CTM apparatus containing water from the acclimation tank. The initial water temperature was recorded, then the water was heated until the fish displayed a behavior response indicating that CTM had been reached. After CTM had been determined, each fish was immediately returned to its original test temperature.

The CTM apparatus for scup consisted of a 9 l round pyrex aquarium with a polyethylene cover. The water was heated at a rate of 1 °C/min by a heater belt wrapped around the tank. A magnetic stirrer provided sufficient water circulation to achieve even heating. A Yellow Springs Instrument Telethermometer Model 46 TUC¹ was used to measure the temperature. For flounder, a larger, 20 l aquarium was used and an air-stone provided water circulation, since a magnetic stir bar on the bottom of the tank disturbed the flounder. The rate of temperature increase for flounder in the larger aquarium was limited to 1 °C/1.5 min by the heating capacity of the apparatus.

The mean test temperature for each group, during 2 weeks prior to CTM measurement, was calculated using data taken at 2-h intervals from continuous temperature recorders. The CTM values were plotted according to the procedure described by Hubbs and Hubbs (1953). This method provided a statistical comparison among the mean CTM values of acclimation groups within each species by graphical comparison of standard errors of the mean.

Results

At extreme temperatures, both *Pseudopleuronectes americanus* and *Stenotomus chrysops* displayed a similar distinct behavior pattern, characterized by rapid darting to the surface, then complete loss of equilibrium and cessation of all movement. This final motionless state was recorded as the end point or CTM. Scup

often exhibited spasms in the posterior section of the body just prior to initiating the darting activity. Cold-acclimated winter flounder occasionally went into convulsive movements following the loss of equilibrium. In general, as the acclimation temperature increased, the activity just prior to CTM became less violent, but the end point remained distinguishable.

The CTM of both species increased with elevated acclimation temperature (Table 1). For winter flounder, a rise in CTM from 26.4° to 32.4°C was observed as the acclimation temperature increased from 4.2° to 23.0°C. For scup, the CTM increased from 30.2° to 35.6°C over an acclimation range 14.8° to 22.2°C. Fig. 1 illustrates this relationship between CTM and acclimation temperature within each species.

In addition, comparison of the CTM-acclimation temperature plot for winter flounder with that of scup, indicates a distinct difference in temperature tolerance. When acclimated to a temperature regime averaging near 15°C, CTM values for both species were similar, 30.2°C for flounder and 30.3°C for scup. However, as the acclimation temperature increased, differences in species tolerance became apparent. Scup acclimation groups at 19.0° and 19.9°C both exhibited higher CTM values than flounder acclimated to 19.4°C; and at acclimation temperatures of 22° to 23°C, these differences became even more pronounced.

Discussion

In the temperate zone estuary, fish populations consist of both resident and migratory species that can exhibit strikingly different temperature responses. The winter flounder *Pseudopleuronectes americanus* and the scup *Stenotomus chrysops* exemplify a resident and a migratory species, respectively, and comparison of CTM for both species illustrates their diverse temperature responses. Scup is a summer immigrant to New England estuaries, residing there from late April to October. As water temperatures fall, scup migrate south to winter off the Chesapeake Bay, spending all of their life in water above 7°C (Bigelow and Schroeder, 1953). In contrast, winter flounder is a year-round resident of New England waters, preferring temperatures between 12° and 15°C during the summer (McCracken, 1963), but spawning during the winter in shallow estuaries where temperatures range from 1° to 6°C (Bigelow and Schroeder, 1953). Winter flounder prefer temperatures from

¹ Mention of specific products herein does not constitute endorsement by the U.S. Environmental Protection Agency.

Table 1. *Pseudopleuronectes americanus* and *Stenotomus chrysops*. Critical thermal maxima (CTM) for 2 marine fishes acclimated to naturally fluctuating temperature regimes

Winter flounder (<i>P. americanus</i>)				Scup (<i>S. chrysops</i>)			
No. of individuals	Temperature range ^a (°C)	Mean acclimation temperature (°C)	Mean CTM (°C)	No. of individuals	Temperature range ^a (°C)	Mean acclimation temperature (°C)	Mean CTM (°C)
24	0-7	4.2	26.4	26	10-19	14.8	30.2
28	12-20	15.0	30.3	26	16-22	19.0	31.9
24	16-23	19.4	30.8	26	15-24	19.9	33.6
29	19-28	23.0	32.4	21	18-25	22.2	35.6

^a Minimum and maximum temperature experienced during 2 weeks of acclimation prior to CTM determination.

10 to 15°C, while scup prefer temperatures above 7°C, and this preference appears to be reflected in their CTM values. Clearly, both species show a rise in CTM with increasing acclimation temperature, but CTM values for scup at the upper acclimation temperatures are significantly higher than those for flounder, indicating that scup are better adapted than winter flounder to survive high temperatures.

Seasonal variations may affect the observed departure of CTM values, since the species were tested at different times of the year. Evidence does exist indicating seasonal variations in thermal tolerance which are independent of acclimation temperature. For example, Hoar (1955) found that the heat resistance of goldfish (*Carassius auratus*) maintained at 20°C during the summer was higher than that of identically acclimated fish during the winter. A similar seasonal variability was reported for young menhaden (*Brevoortia tyrannus*) (Lewis and Hettler, 1968). In our study however, scup tested in November, when their tolerance should be low, exhibited a significantly higher CTM than flounder tested in June, when their tolerance should be high. Either the pattern is reversed from that documented for other species, or in spite of seasonal variations, scup are better adapted for high temperature survival than winter flounder.

There is evidence that aquatic organisms respond differently to thermal stress when maintained under fluctuating acclimation temperatures which simulate the natural environment, as opposed to constant acclimation temperatures (Brett, 1946; Hubbs, 1964). According to Hutchinson and Ferrance (1970), frogs (*Rana pipiens*) acclimated more rapidly under a fluctuating temperature regime. Hoss et al. (1974a) showed that larval pinfish

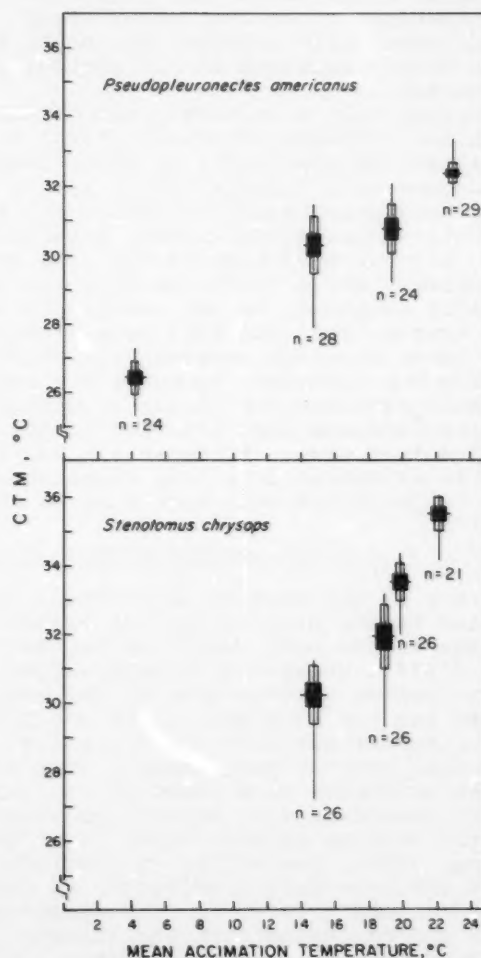


Fig. 1. *Pseudopleuronectes americanus* and *Stenotomus chrysops*. CTM-acclimation temperature plots for winter flounder and scup. Vertical line represents range, horizontal line mean CTM; black bar ± 2 standard errors and open bar ± 1 standard deviation; n: number of individuals

(*Lagodon rhomboides*) had greater tolerance to thermal shock under a cycling 7° to 13°C regime than under constant 10°C acclimation. Otto (1974) showed that mosquitofish (*Gambusia affinis affinis*) exhibited higher CTM in a fluctuating acclimation cycle than that anticipated at a constant temperature equivalent to the mean of the fluctuation, but lower than that at a constant temperature equivalent to the peak of the fluctuation. Heath (1963) found that the CTM of sea-run cutthroat trout (*Salmo clarki clarki*) in a 10° to 20°C cycle was the same as that for fish maintained at constant 20°C, the peak of the fluctuation. Since the choice of cycling or constant acclimation regimes can affect the outcome of thermal tolerance studies, we feel that a regime which tracks the temperature fluctuations of ambient water would yield more valid information for inference about responses in the natural environment.

Rather than a standard rate of heating such as 1 C°/min, Hutchison (1961) emphasizes the importance of using a rate of temperature increase which allows the deep-body temperature to follow the rise in water temperature without substantial lag. If this condition is met, the CTM of animals which differ in size can be validly compared. In our study, the water temperature increased more slowly in the large aquarium necessary to accommodate the flounder; however, a slower rate is required for larger organisms to insure complete heat transfer to the deep-body tissues. A comparison was made of the estimated deep-body temperature lag for each species. According to Rose (1967):

$$\text{lag (C°)} = \frac{\text{rate of water temperature change (C°/min)}}{k}$$

where k is the cooling coefficient obtained from a plot of cooling coefficients versus body weight in Stevens and Fry (1974). Using the average weight for each species to determine k , the estimated lag for scup was 1.0 C° and that for flounder was 0.96 C°. The actual lag for both species was probably less since these estimates were based on cooling coefficients, and in aquatic poikilotherms heating is more rapid than cooling (Rose, 1967). Therefore, we concluded that the necessary conditions, as defined by Hutchison (1961), for CTM determination and comparison between animals which differ in size, were met.

How useful are laboratory determinations of CTM for predicting thermal discharge effects of steam-generating plants upon adult and juvenile fish populations? There is no doubt that CTM conditions can plausibly occur near a power-plant

discharge. However, Coutant (1970) argues that the laboratory CTM determination is unsuitable for prediction since the end point, expressed as a temperature, is arrived at by varying both time and temperature. To illustrate this difficulty, Hoss et al. (1974b) pointed out that 15°C-acclimated larval menhaden have a CTM of 30°C, but some will survive a thermal shock of that magnitude if the exposure time is 10 min or less. Obviously predictions based on CTM are limited only to field situations where the rate of temperature increase is the same as that of the laboratory determination, an infrequent occurrence.

While the CTM determination is not appropriate for predictive purposes, it remains a simple and rapid technique to obtain preliminary and comparative information about how different organisms respond to temperature. CTM data indicates differences in temperature sensitivity among species, as has been used here and by Hoss et al. (1974b). Such studies provide background information for experiments specifically designed to predict the impact of power plants upon the environment. Certainly for these purposes, experiments must be conducted on the most sensitive organisms likely to be affected. CTM determinations on organisms acclimated to relatively high temperatures, where response departures occur, will pinpoint the most sensitive species.

Acknowledgements. We thank A. Neves for his technical assistance, and Dr. D. Miller for his constructive criticism of the manuscript.

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Date of final manuscript acceptance: December 17, 1976. Communicated by M.R. Tripp, Newark